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Mark IV-A DSCC (Magellan-Era) Telemetry System Description

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This article provides an update to the description of the Deep Space Communications Complex portion of the Mark IV-A Telemetry System. This system, described in [1], is currently implemented at all signal processing centers. The upgrade of the telemetry system was undertaken primarily in support of the Voyager–Neptune Encounter and the Magellan mission. The Mark III Telemetry System is the predecessor of the Mark IV-A system and is described in [2].

I. Introduction

Implementation of the Deep Space Network (DSN) Mark IV-A (Magellan-era) Telemetry System was completed in early 1989 in time to support the Magellan launch and Voyager–Neptune Encounter. The DSCC portion of the DSN Telemetry System has been significantly changed in four subsystems as a result of the Magellan-era and Voyager–Neptune Encounter implementation.

A. Antenna Mechanical Subsystem

The 64-m subnet has undergone a major modification consisting of the enlargement of each of the three antennas to 70 m. This was done specifically to support the Voyager–Neptune Encounter and provided a gain increase of 2 dB at 8420 MHz (X-band) through enlargement and surface shape improvement.

B. Receiver-Exciter Subsystem

The Magellan Project required a telemetry system lockup within 60 seconds to maximize data return for an orbital mission that requires the downlink to be acquired twice during each orbit of 3.15 h for three orbits per pass over a primary mission period of 250 days. To achieve this, the receiver was upgraded to provide automatic acquisition and tracking of the downlink carrier. This required the Deep Space Network to add fast Fourier transform (FFT) automatic signal acquisition hardware and firmware to all receivers. In addition, the Magellan orbit phase produces Doppler offsets which must be removed during tracking to maintain carrier lock and minimize signal-to-noise ratio (SNR) degradation. This required adding a programmable frequency synthesizer to the Block III receiver carrier loop and adding downlink tuning firmware to all receivers (Block III and Block IV).

C. Telemetry Subsystem

Several significant changes were made in the telemetry subsystem to meet Magellan requirements placed on the Deep Space Network.

The baseband assembly (BBA) was upgraded (1) to improve low data rate performance at data rates down to 10 b/s and (2) to improve acquisition time when the

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subcarrier frequency is not precisely known. The existing acquisition bandwidth was 0.1 Hz, but the expected uncertainty approached 4 Hz. This was achieved by widening the acquisition bandwidth to 5 Hz or greater, depending on the data rate. A fast Fourier transform (FFT) was added to the BBA to meet the requirement of reducing acquisition time to 36 seconds or less for high data rates. Actual acquisition times have been far better than this, ranging from 12 to 20 seconds, depending on the accuracy of subcarrier predictions.

The maximum-likelihood convolutional decoder (MCD) was upgraded to provide processing of telemetry data at rates (from the previous 250 kb/s) up to 270 kb/s. This was necessary to support the maximum Magellan data rate of 268.8 kb/s. A serial data output (with its associated clock) was added to the MCD to provide an input to the frame synchronizer (described below). The MCD will now accept a node synchronization change command, which provides a quick switch over to the correct node in the event of an MCD false lock.

An upgraded MCD was added to Channel 2 of Telemetry Groups 3 and 4 to support concurrent processing of two coded streams of telemetry data in each group.

A frame synchronizer was added to both channels of groups 3 and 4 to enable frame synchronization of Magellan telemetry data. This is especially important for Magellan orbital data, since the data downlinked at 268.8 kb/s is recorded only at the Signal Processing Centers (SPCs) and then mailed back to JPL for analysis, which may take place as much as two weeks after recording. If the DSN is able to frame synchronize the high-rate data, then it is almost certain that good data are being recorded.

D. Ground Communications Facility (GCF) Data Records Subsystem

New equipment was added to the GCF subsystem to process and record Magellan telemetry data. The designation for this equipment is DSCC Data Records (DDR) assembly, which includes a high-density tape recorder that will record in excess of one hour of data at 268.8 kb/s on a single reel. The DDR formats the telemetry data into Standard Formatted Data Units (SFDUs), time-tags it with Earth-received time, stores it on magnetic tape, and transmits it to JPL in real time (except for 268.8 kb/s data which is stored only on magnetic tape and mailed to JPL).

Implementation of these changes, combined with previous capabilities, has prepared the network to support the following missions:

(1) Galileo

(2) Giotto Extended Mission

(3) International Cometary Explorer (ICE)

(4) Magellan

(5) Pioneers 6 through 8

(6) Pioneers 10 and 11

(7) Pioneer Venus

(8) Ulysses

(9) Voyager Interstellar Mission

II. Key Characteristics

The key characteristics of the DSCC portion of the Mark IV-A Telemetry System are:

(1) Auto acquisition and tracking of downlink carrier

(2) Complete telemetry system lockup within one minute at high data rates

(3) Process coded data at rates up to 270 kb/s

(4) Baseband combining for up to six antennas

(5) Four complete groups of telemetry equipment at each complex, each with the capacity to support any one of the above missions except for Magellan, which can only be supported by two of the four groups

(6) Demodulation of Manchester coded (Biϕ-L) or NRZ-L or NRZ-M data

(7) Symbol synchronization of demodulated data

(8) Maximum-likelihood decoding of short-constraint-length convolutional codes and sequential decoding of long-constraint-length convolutional codes

(9) Frame synchronization

(10) Precise measurement of received signal level and system noise temperature

(11) Centralized control by (and real-time reporting to) the monitor and control subsystem

(12) Production of digital telemetry original data record (ODR) for each telemetry group with playback via local manual control; reduced playback rate for higher data rates as required

Automatic acquisition of the carrier, telemetry system lockup in one minute, and handling of increased data rates have been implemented to meet Magellan requirements. New equipment providing frame-synchronization, formatting, and storage of high data rates in real time also meet Magellan Project requirements.

III. Project Data Rate and Coding Requirements

Requirements for new and existing deep space missions are listed in Table 1. The new missions to be supported during the Magellan era are Galileo, Giotto Extended Mission, Magellan, and Ulysses. The next section shows how deep-space mission requirements will be met.

IV. DSCC Conceptual Description

The DSCC block diagram in Fig. 1 provides a conceptual description of the portion of the Mark IV-A Telemetry System to be located at each DSCC. There will be one 70-m antenna and two 34-m antennas. The 70-m and 34-m standard antennas will be able to receive an S-band (2200–2300 MHz) plus an X-band (8400–8440 MHz) carrier simultaneously. Each of the 34-m high-efficiency antennas will receive one X-band (8400–8440 MHz) carrier or one S-band (2270–2300 MHz) carrier; however, the S-band (2270–2300 MHz) system temperature is higher than the 34-m standard antennas (see Table 2).

Table 2 gives the radio frequency reception characteristics for these antennas and indicates the distribution of masers, high-electron-mobility transistors (HEMTs), and field-effect transistors (FETs). The 70-m antennas will be equipped exclusively with masers whereas the 34-m antennas will also have HEMTs and FETs. At the 34-m standard antennas, the masers will provide deep-space support while the FETs support near-Earth missions with their broader (2200–2300 Mhz) reception bandwidth requirements. New HEMTs have been installed at the 34-m high-efficiency antennas to support deep-space missions as a backup to the masers. New Block II-A X-band (8400–8440 MHz) masers have been provided for all 70-m antennas and 34-m high-efficiency antennas giving lower system temperatures than in the Mark III DSN. Also, the 34-m high-efficiency antennas provide an increase in X-band (8400-8440 MHz) gain over that of the existing 34-m standard antennas.

Also shown in Fig. 1 is a block diagram representation of the receiver-exciter and telemetry subsystems. Modified Block III and Block IV receivers will be used to receive and detect baseband signals. The Block III and Block IV receivers have been modified to provide automatic acquisition and tracking of the downlink carrier leading to a 60-second overall lockup in conjunction with the telemetry subsystem. The telemetry subsystem is arranged to provide four telemetry groups, any of which can process data from any receiver and therefore from either a near-Earth mission or deep-space spacecraft. All groups will include one or two maximum-likelihood convolutional decoders (MCDs) and one telemetry processor assembly (TPA). The MCDs have been modified to increase the data processing rate to 270 kb/s and to provide a serial output to the frame synchronizers. Telemetry Groups 3 and 4 are equipped with a modified BBA, which will include the functions of baseband combining, subcarrier demodulation and symbol synchronization. Upgrades to the BBA included widening the acquisition bandwidth and reducing acquisition time.

Figure 2 is a functional block diagram of the BBA. Any combination of receiver outputs can be input to either subcarrier demodulator; or any single receiver output can be routed to either subcarrier demodulator, bypassing the combining function. The monitor and control function is performed from the TPA with no manual intervention required. The BBA is designed to accommodate NRZ-L, NRZ-M, or Biϕ-L symbol formats, subcarriers up to 2 MHz, and data rates from 4 s/s to 1 Ms/s with subcarrier, up to 4 Ms/s (NRZ) without subcarrier or up to 2 Ms/s for Biϕ-L. When the BBA is operated in the mode which combines the 70-m and two 34-m antenna basebands, a nominal system signal degradation of about 0.3 dB will result at the highest data rates. This includes an allowance for waveform, spectrum correlation and symbol timing losses and represents an improvement over the Mark III system. The soft symbol output from the BBA is passed to an MCD for decoding. The decoded bits from the MCD are then passed to one of two places:

(1) a frame synchronizer where the data is synchronized to the transfer frame level and sent, frame-by-frame, to the DDR for formatting, or

(2) the TPA where it is asynchronously formatted for transmission to JPL.

Telemetry Groups 1 and 2, as shown in Fig. 1, both include subcarrier demodulator assemblies (SDAs) and symbol-synchronizer assemblies (SSAs) as well as an MCD and a TPA. Except for the MCDs, which have been modified as indicated above, the hardware and configuration in Groups 1 and 2 remains unchanged for the Magellan era.

The 70-m and 34-m antennas can be arrayed by combining baseband signals and performing subcarrier demodulation and symbol synchronization in the BBA in either Telemetry Group 3 or Telemetry Group 4. The combined signal is then decoded in the maximum-likelihood convolutional decoder. Subsequently it is either formatted for transmission to JPL in the telemetry processor assembly or sent to the frame synchronizer and then to the DSCC data records assembly (DDR) for formatting and transmission to JPL. When combining is not required, outputs from an antenna may also be routed to a subcarrier demodulator assembly (Groups 1 and 2) or to either BBA (Groups 3 and 4).

Any of the telemetry equipment groups can accept two data streams. In any group, one data stream is processed by channel 1 and one by channel 2. The performance parameters for channels 1 and 2 are listed in Tables 3 and 4, respectively. Comparing Table 1 with Table 3 and Table 4, it may be noted that Data Stream 1 in Table 1 is processed by channel 1, while Data Stream 2 is processed in channel 2. Also note that Groups 3 and 4 provide higher data rate capability (for example, for convolutionally coded data: 270 kb/s versus 135 kb/s) and higher subcarrier frequency capability (2 MHz versus 1 MHz). Note further that a second MCD has been added to Groups 3 and 4. This MCD was added in channel 2 during the Magellan-era upgrade and provides the capability of concurrently processing two convolutionally coded data streams (a Magellan requirement).

Future upgrades to the telemetry system include new receivers with wider bandwidths, new TPAs, MCD replacement, addition of a Reed-Solomon decoder and provision for high-rate recording. Implementation of this new equipment will enable processing of telemetry data at rates up to 2.2 Mb/s for a single stream or an aggregate of 3 Mb/s in each telemetry group. A fifth telemetry group will also be added, thus enabling the integration of the 26-m subnet into the SPCs for increased operational effectiveness. Future planned missions will require these additional improvements.

References

[1] D. L. Ross, "Mark IV-A DSCC Telemetry System Description," *TDA Progress Report 42-83*, vol. July–September 1985, Jet Propulsion Laboratory, Pasadena, California, pp. 92–100, November 15, 1985.

[2] E. C. Gatz, "DSN Telemetry System Mark III-77," *DSN Progress Report 42-49*, Jet Propulsion Laboratory, Pasadena, California, pp. 4–10, February 15, 1979.

Table 1. Single link requirements for deep-space missions

Mission	Data Stream 1	Data Stream 2
Galileo	Convolutionally coded; K=7, R=1/2; NRZ-L; up to 134.4 kb/s; Subcarrier: 360 kHz; Carrier: 8415/8420.4 MHz or Convolutionally coded; K=15, R=1/4; NRZ-L; 115.2 or 134.4 kb/s; Subcarrier: 720 kHz; Carrier: 8415/8420.4 MHz or Convolutionally coded; K=7, R=1/2; NRZ-L; up to 40 kb/s; Subcarrier: 22.5 kHz for data rates lower than 7.68 kb/s, 360 kHz for rates $\geq$ 7.68 kb/s; Carrier: 2295/2296.5 MHz	Uncoded; NRZ-L; 40 b/s; Subcarrier: 22.5 kHz; Carrier: 2295/2296.5 MHz
Giotto Extended Mission	Convolutionally coded; NRZ-L; K=7, R=1/2; Subcarrier: 46.080 kHz for data rate of 360 b/s, 276.480 kHz for data rates of 5,760 b/s, 23,040 b/s and 46,080 b/s; Carrier: 2298.703704 or 8428.580248 MHz or Reed-Solomon* and convolutionally coded; NRZ-L; K=7, R=1/2; Subcarrier: 276.480 kHz for data rates of 5,760 b/s, 23,040 b/s, and 46,080; Carrier: 2298.703704 or 8428.580248 MHz	Uncoded; NRZ-L; Subcarrier: 46.080 kHz for data rate of 360 b/s; Carrier: 2298.70374 or 8428.580248 MHz or Reed-Solomon* coded; NRZ-L; Subcarrier: 276.480 kHz for data rates of 5,760 b/s, 23,040 b/s, and 46,080 b/s; Carrier: 2298.703704 or 8428.580248 MHz
ICE	Convolutionally coded; K=24, R=1/2; NRZ-L; 64 b/s; Subcarrier: 1024 Hz; Carrier: 2270.4 and 2217.5 MHz or Convolutionally coded; K=24, R=1/2; 512 to 2048 b/s; Biϕ-L; Carrier: 2270.4 and 2217.5 MHz	
Magellan	Convolutionally coded; NRZ-L; K=7, R=1/2; 115.2 or 268.8 kb/s; Subcarrier: 360 or 960 kHz for 115.2 kb/s data rate, 960 kHz for 268.8 kb/s; Carrier: 8425.8 MHz	Convolutionally coded; NRZ-L; K=7, R=1/2; 40 or 1200 b/s; Subcarrier: 22.5 kHz; Carrier: 2297.9 or 8425.8 MHz
Pioneers 6–8	Uncoded; NRZ-M; 8 to 512 b/s; Subcarrier: 512 Hz for 8 to 64 b/s, 2048 Hz for 128 b/s; Carrier: 2292.407407 MHz	
Pioneers 10/11	Uncoded; NRZ-L; 8 to 2048 b/s; Subcarrier: 32.768 kHz; Carrier: 2292.407407 MHz or Convolutionally coded; K=32, R=1/2; NRZ-L; 8 to 2048 b/s; Subcarrier: 32.768 kHz; Carrier: 2292.407407 MHz	
Pioneer Venus	Uncoded; NRZ-L; 8 to 4096 b/s; Subcarrier: 16 kHz; Carrier: 2293.888 or 2294.259 MHz or Convolutionally coded; K=32, R=1/2; NRZ-L; 8 to 2048 b/s; Subcarrier: 16 kHz; Carrier: 2293.888 or 2294.259 MHz	
Ulysses	Convolutionally coded; NRZ-L; K=7, R=1/2; 128 b/s to 8,192 b/s; Subcarrier: 65,536 Hz for rates up to 1,024 b/s, 131,072 Hz for rates of 2,048 b/s or greater; Carrier: 2293.148148 or 8408.209876 MHz	
Voyager	Convolutionally coded; K=7, R=1/2; NRZ-L; 10 to 115,000 b/s; Subcarrier: 360 kHz Carrier: 8420.432097 MHz	Uncoded; NRZ-L; 46.667 b/s; Subcarrier: 360 kHz; Carrier: 8420.432097 MHz or Uncoded; NRZ-L; 46.667 b/s; Subcarrier: 22.5 kHz; Carrier: 2296.481481 MHz

*Reed-Solomon data are not presently decoded at the DSN; only convolutionally encoded data are decoded at the DSN.

Table 2. Radio frequency reception characteristics

Parameter	Antenna		
	70 meter	34-meter standard	34-meter high efficiency
Frequency range, MHz			
S-band	2270-2300	2200-2300	2270-2300
X-band	8400-8440	8400-8440	8400-8440
Gain, dBi, non-diplexed mode			
S-band	63.34 ± 0.01	$56.1^{+0.3}_{-0.7}$	56.0 ± 0.2
X-band	$74.17^{+0.2}_{-0.2}$	66.2 ± 0.6	68.3 ± 0.2
System noise temp., K zenith, non-diplexed mode			
S-band with maser	18.5 ± 2	21.5 ± 2.5	
S-band with FET		110 ± 10	55 ± 5 (DSS 45/65)
S-band with HEMT			36 ± 3 (DSS 15)
X-band with maser	20.6 ± 2	21.5 ± 2.5	19.7 ± 2.0
X-band with HEMT			36 ± 6

The above values are representative only. For a complete set of specifications, see DSN Flight Project Interface Design Handbook, Document 810-5, Rev. D, Volumes 1 and 2.

Table 3. DSCC telemetry s/s channel capabilities (telemetry groups 1 and 2)

Functions	Channel 1	Channel 2
Baseband Combining	N/A	N/A
Subcarrier Demodulation	100 Hz to 1 MHz, square wave or sine wave	100 Hz to 1 MHz square wave or sine wave
Symbol Synchronization	6 s/s to 268.8 ks/s	6 s/s to 268.8 ks/s
Data Format	NRZ-L, NRZ-M, Biϕ-L	NRZ-L, NRZ-M, Biϕ-L
Sequential Decoding	K=24 or 32; R=1/2; frame length selectable; 6 s/s to 20 ks/s	N/A
Maximum-Likelihood Convolutional Decoding	K=7; R=1/2 or 1/3; 10 b/s to 134.4 kb/s	N/A
Uncoded	6 b/s to 268.8 kb/s*	6 b/s to 268.8 kb/s*

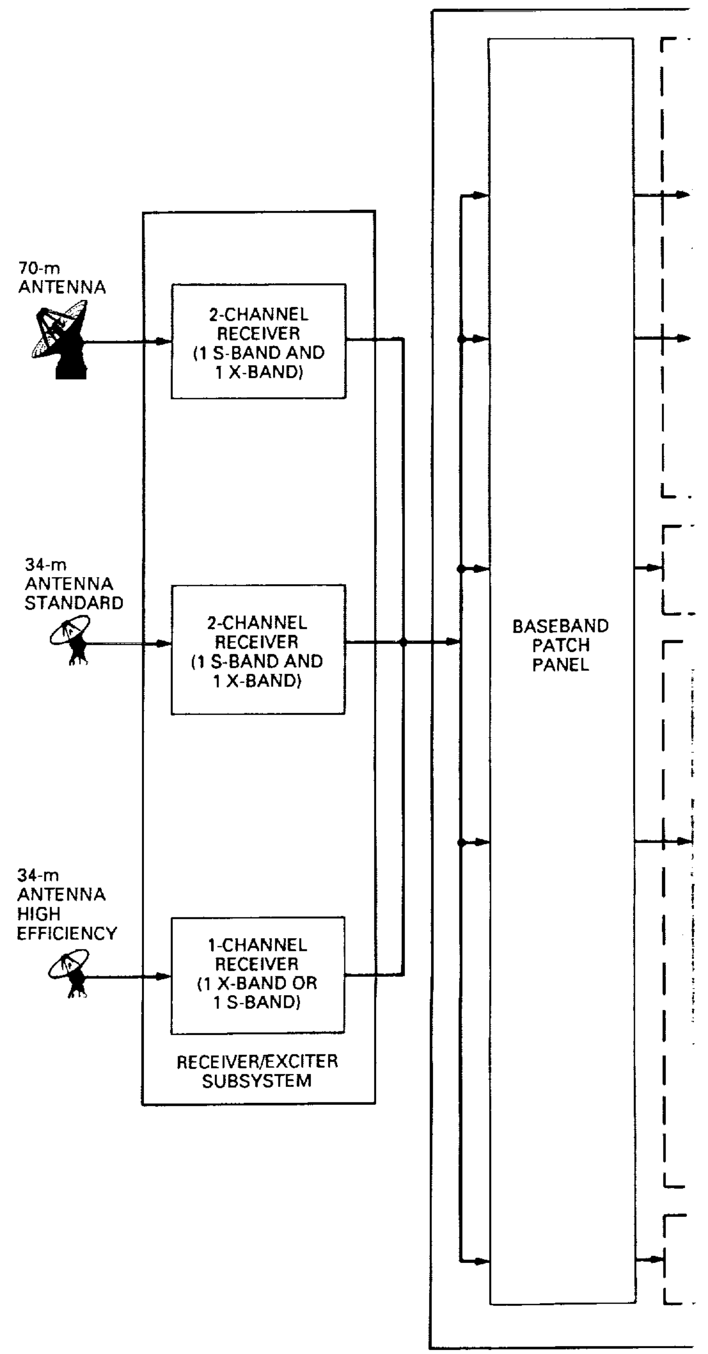
*Record only with non-real-time playback above 250 kb/s.

Table 4. DSCC telemetry s/s channel capabilities (telemetry groups 3 and 4)

Functions	Channel 1	Channel 2
Baseband Combining	Up to six basebands	N/A
Subcarrier Demodulation	10 kHz to 2 MHz, square wave or sine wave	10 kHz to 2 MHz square wave or sine wave
Symbol Synchronization	4 s/s to 4 Ms/s	4 s/s to 4 Ms/s
Data Format	NRZ-L, NRZ-M, Biϕ-L	NRZ-L, NRZ-M, Biϕ-L
Sequential Decoding	K=24 or 32; R=1/2; frame length selectable; 6 s/s to 20 ks/s	N/A
Maximum-Likelihood Convolutional Decoding	K=7; R=1/2 or 1/3; 10 b/s to 134.4 kb/s*	N/A
Frame Synchronization (Transfer Frame Level)	Up to 1.6 Mb/s	Up to 1.6 Mb/s
Uncoded	4 b/s to 500 kb/s*	4 b/s to 500 kb/s*

*Record only with non-real-time playback above 250 kb/s.

FOLDOUT FRAME 1.



FOLDOUT FRAME 2.

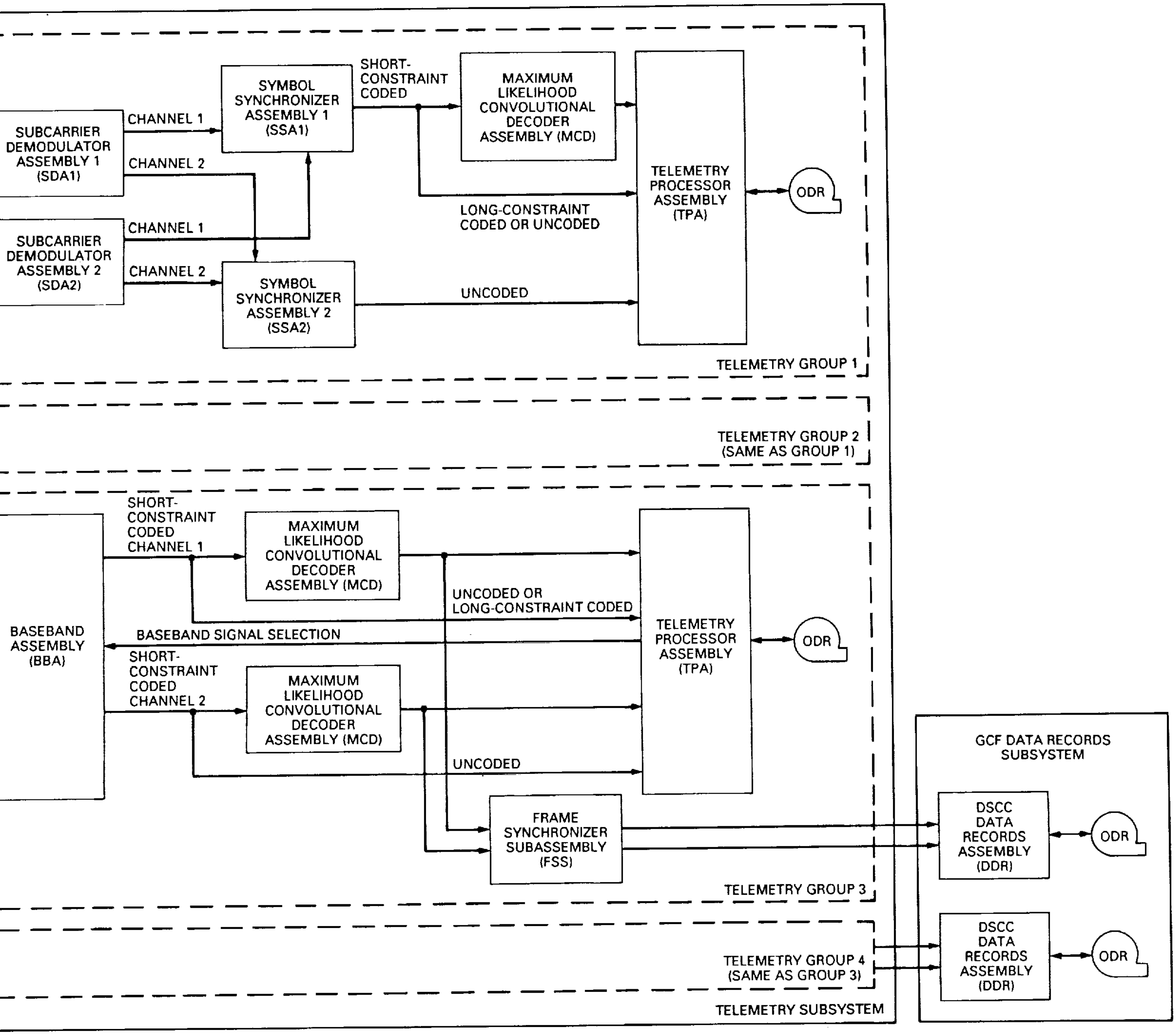


Fig. 1. Telemetry System: DSCC block diagram.

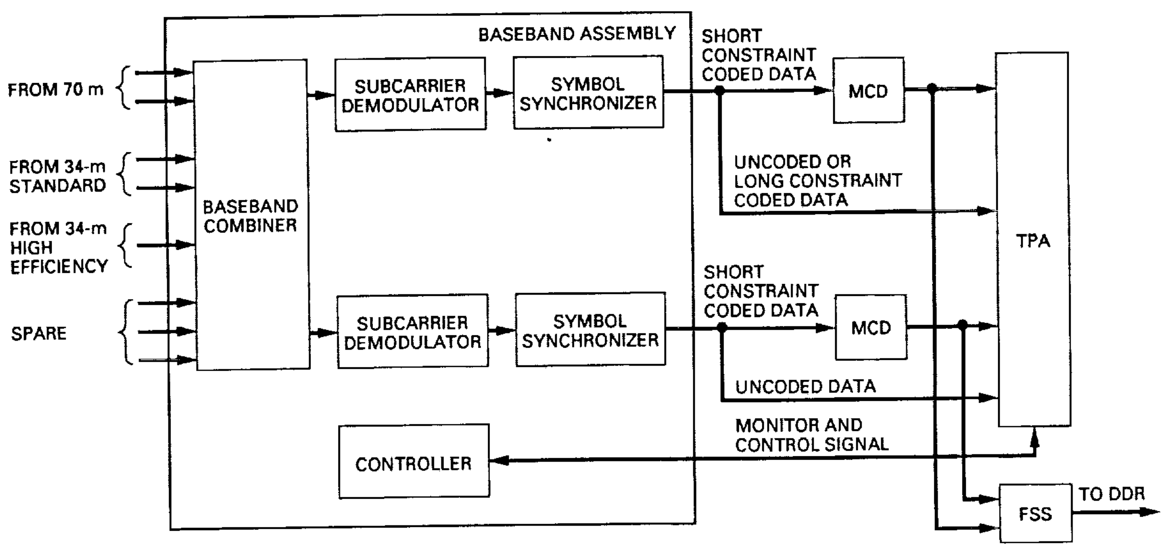


Fig. 2. Baseband assembly functional block diagram.

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